CHAPTER 9: STORAGE-VOLUME REQUIREMENTS

As a watershed develops, there is potential for an increase in runoff and peak discharges. One of the most common techniques for minimizing the increase in runoff and discharges is the requirement of the construction of a detention pond. This section will cover the volume requirements and the routing techniques used in designing a detention pond.

Urban Hydrology for Small Watersheds, TR-55 (reference 46) contains a quick method for estimating the size of a detention pond. Figure 9.1 shows a relationship between the peak inflow and peak outflow to the storage volume and runoff volume. By knowing three values (such as runoff volume, peak inflow, and peak outflow), it is possible to estimate the fourth value (storage volume required).

In examples 7.2 and 7.3, a volume of runoff and a peak flow had been computed for a particular site. If peak outflows are to be reduced at this site, figure 9.1 can be used to estimate the storage required.
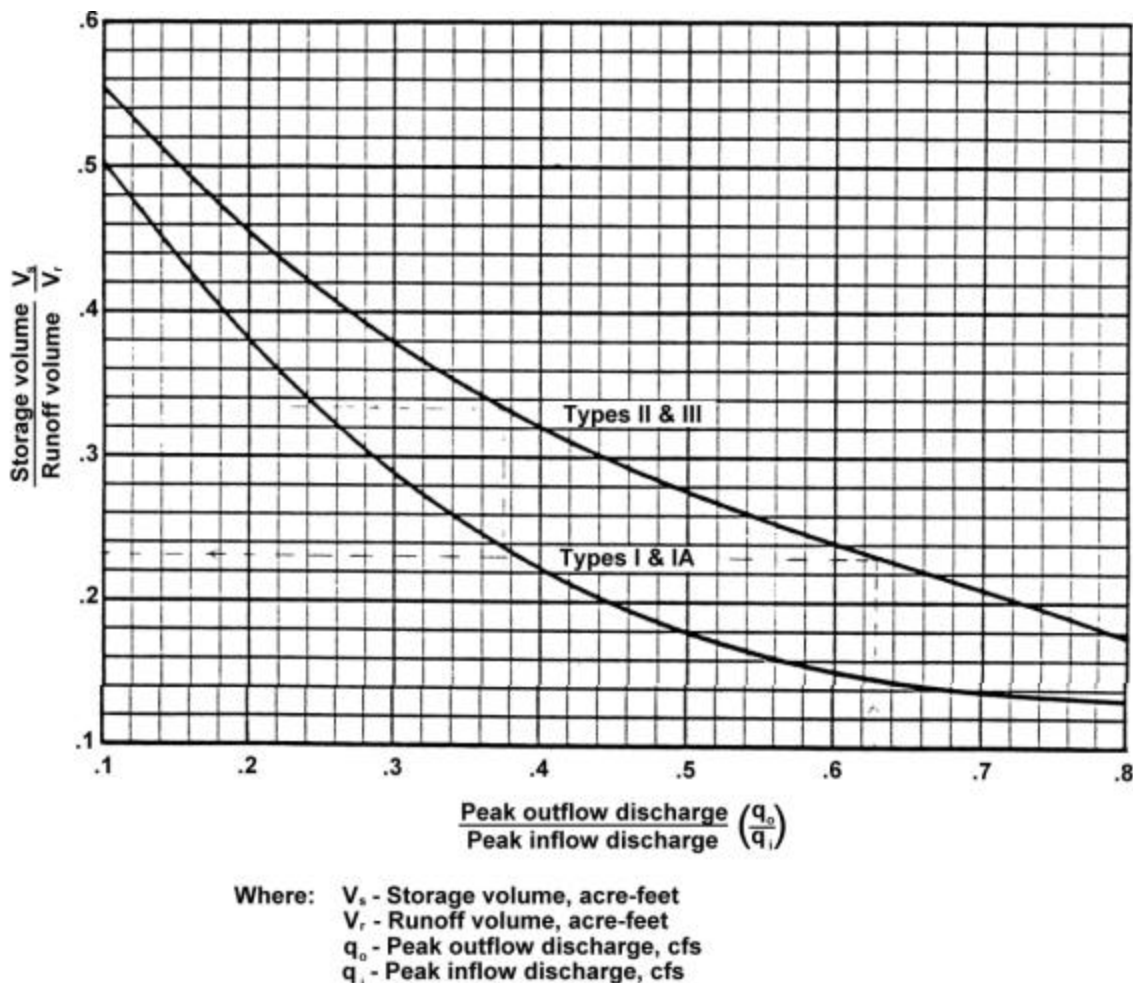

Where: V_s - Storage volume, acre-feet
V_r - Runoff volume, acre-feet
q_o - Peak outflow discharge, cfs
q_i - Peak inflow discharge, cfs

Figure 9.1 - Approximate Detention Basin Routing

(Source: Soil Conservation Service, Reference 46)

Example 9.1: The volume of runoff is computed to be 2.79 sq.mi.-inches (148.8 acre-feet). The peak inflow is 430 cfs. Estimate the storage volume needed to reduce the peak outflow to 270 cfs.

- Peak inflow   = 430 cfs
- Peak outflow   = 270 cfs
- Ratio of outflow to inflow   = 270 cfs/ 430 cfs = .628
- From figure 9.1, using type II rainfall,
  ratio of storage volume/runoff volume   = **0.233**

- Required storage volume   = 0.233 x 2.79 sq.mi.-inches
                                        = 0.650 sq. mi. - inches
                                        = 34.7 acre-feet use **35.0 acre - feet**

Example 9.2: If a detention pond containing 50 acre-feet of storage was being proposed on the above watershed, estimate the impact on the peak outflow.

- runoff volume = 2.79 sq.mi.-inches = 148.8 acre-feet
- storage volume provided = 50 acre-feet
- ratio of storage volume/runoff volume = 50/148.8 = 0.336
- from figure 9.1, peak outflow/peak inflow = **.372**
- peak inflow - 430 cfs
- thus: peak outflow = 0.372 x 430 cfs = **160 cfs**

where: V_s **- Storage volume, acre-feet**
                 V_r **- Runoff volume, acre-feet**
                 q_o **- Peak outflow discharge, cfs**
                 q_i **- Peak inflow discharge, cfs**

It is noted in the TR-55 manual that this procedure will result in storage volume requirements that are conservative. This technique may overestimate the volume requirement by as much as 25 percent. A detailed hydrologic analysis and routing would provide a more accurate estimate of the storage requirements and peak outflow.

ROUTING TECHNIQUE

There are different methods available to perform a routing through a detention pond. The primary idea behind a routing is to determine the impact that the detention pond will have on the inflowing flood peak by using the **continuity equation.** The equation can be thought of as **Inflow** (to the detention basin) minus **outflow** (from the detention basin) equals **change in storage** (in the detention basin). In equation form:

$$dt\, (I_{ave} - O_{ave}) = S \tag{42}$$

where: **dt**   - a time interval
              I_{ave} - average inflow during time interval
              O_{ave} - average outflow during time interval
              S   - change in storage during time interval

Storage - Indication method

Of the various methods available to route a flood flow through a detention pond, the storage-indication method will be the only one discussed briefly in this guidebook. If additional information is needed on other routing techniques, it is suggested that the reader refer to the SCS's National Engineering Handbook Section 4 Hydrology (reference 49).

Equation 42 that has been rearranged is used in the storage-indication method:

$$I_{ave} + S_1/dt - O_1/2 = S_2/dt + O_2/2 \tag{43}$$

where: S_1 - is the storage at t_1 (the beginning of the routing interval).
O_1 - is the outflow at t_1
S_2 - is the storage at t_2 (the end of the routing interval).
O_2 - is the outflow at t2.
I_{ave} - is the average inflow for the time interval $(I_1 + I_2)/2$.

The following steps can be used to route a flood hydrograph through a detention basin by "hand", using the storage indication method.

1. **Develop a rating curve for the outlet structure**. The rating curve can be developed using procedures discussed in Chapter 8. The rating curve will show the discharge for a given elevation for the outlet structure. The discharge should be expressed in units that are consistent with the storage volume. Units of acre-feet will result in numbers that are considerably smaller than if cubic feet are used. (One acre-foot = 43560 cubic feet, one cubic foot/second = .083 acre-feet /hour).

2. **Develop storage-elevation curve for the detention pond**. The amount of storage available within the detention pond is computed for a range of elevations. The storage units should be consistent with discharge rating curve (such as acre-feet or cubic feet).

3. **Combine the curves developed** in steps 1 & 2 to form a relationship between storage and discharge. Table 9.1 is an example of storage volumes and discharges for a range of elevations.

Table 9.1 - Storage-Discharge Relationship

Elevation	Storage	Discharge
	100,000	
feet	cubic feet	cfs
604.3	0.0	0
606.0	8.3	61
607.0	13.1	74
608.0	17.9	87
609.0	23.1	100
610.0	28.3	200
611.0	33.5	420
612.0	38.8	750

4. **Select a routing interval (dt)**. Typically for small watersheds the routing interval will be less than an hour, usually 0.25 hour to 0.5 hour.

5. **Prepare the working curves**, and plot O_2 versus $S_2/dt + O_2/2$ (figure 9.2). Using the storage-discharge relationship in Table 9.1, an example working curve is developed below.

**Table 9.2 - Working Curve (dt = 0.25 hrs. = 900 seconds)**

Elevation	Discharge O_2*	Storage S_2*	$O_2/2$	S_2/dt	$S_2/dt +O_2/2$
604.3	0	0.0	0	0	0
606.0	61	8.3	30	**922	952
607.0	74	13.1	37	1456	1493
608.0	87	17.9	44	1989	2023
609.0	100	23.1	50	2567	2617
610.0	200	28.3	100	3144	3244
611.0	420	33.5	210	3722	3932
612.0	750	38.8	375	4311	4686

NOTES: * 02 is the outflow, cfs at the given elevation.

       S2 is the storage 100,000 cubic feet, at the given elevation.

      ** S2/dt = 830,000 cubic ft/900 seconds = 922 cubic ft/second.
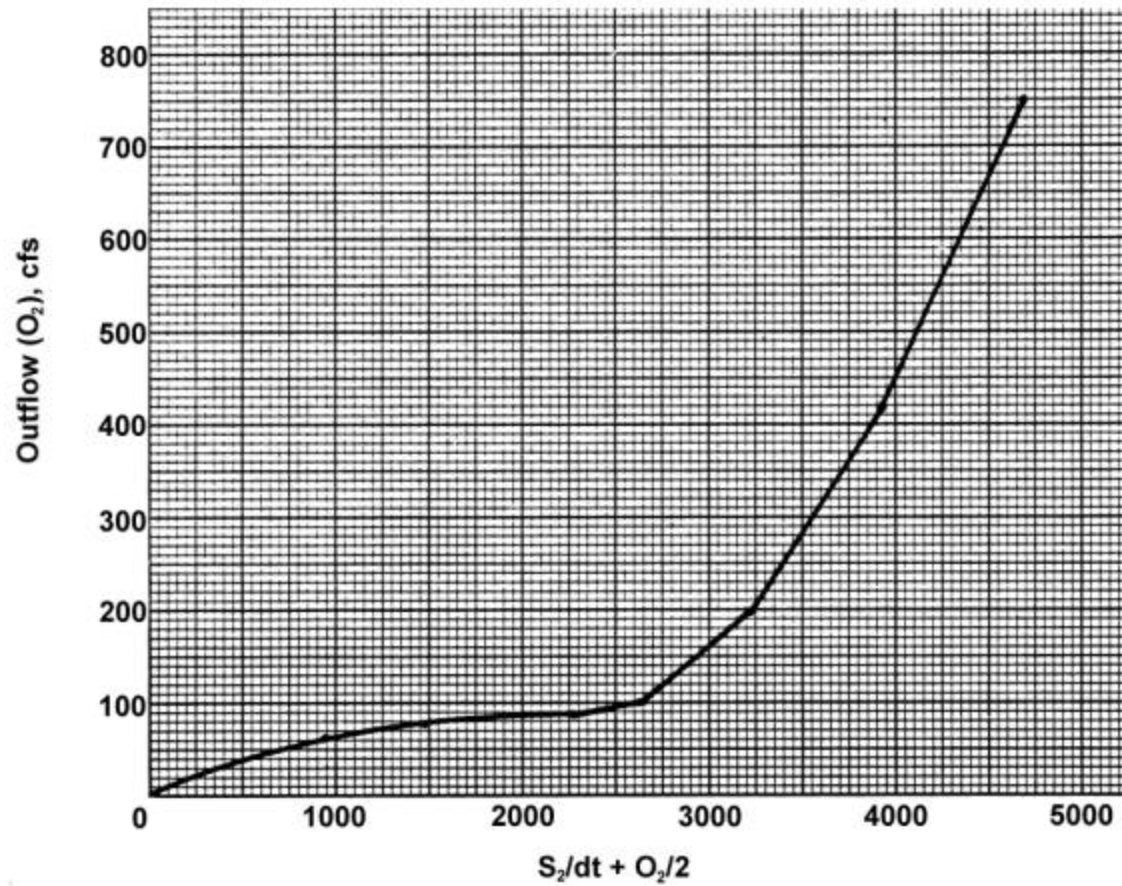
Where: **O_2 - Outflow in cfs**
               S_2/dt - storage/routing interval, cubic feet/second

Figure 9.2 - Working Curve For Example

Where: O_2 - Outflow in cfs

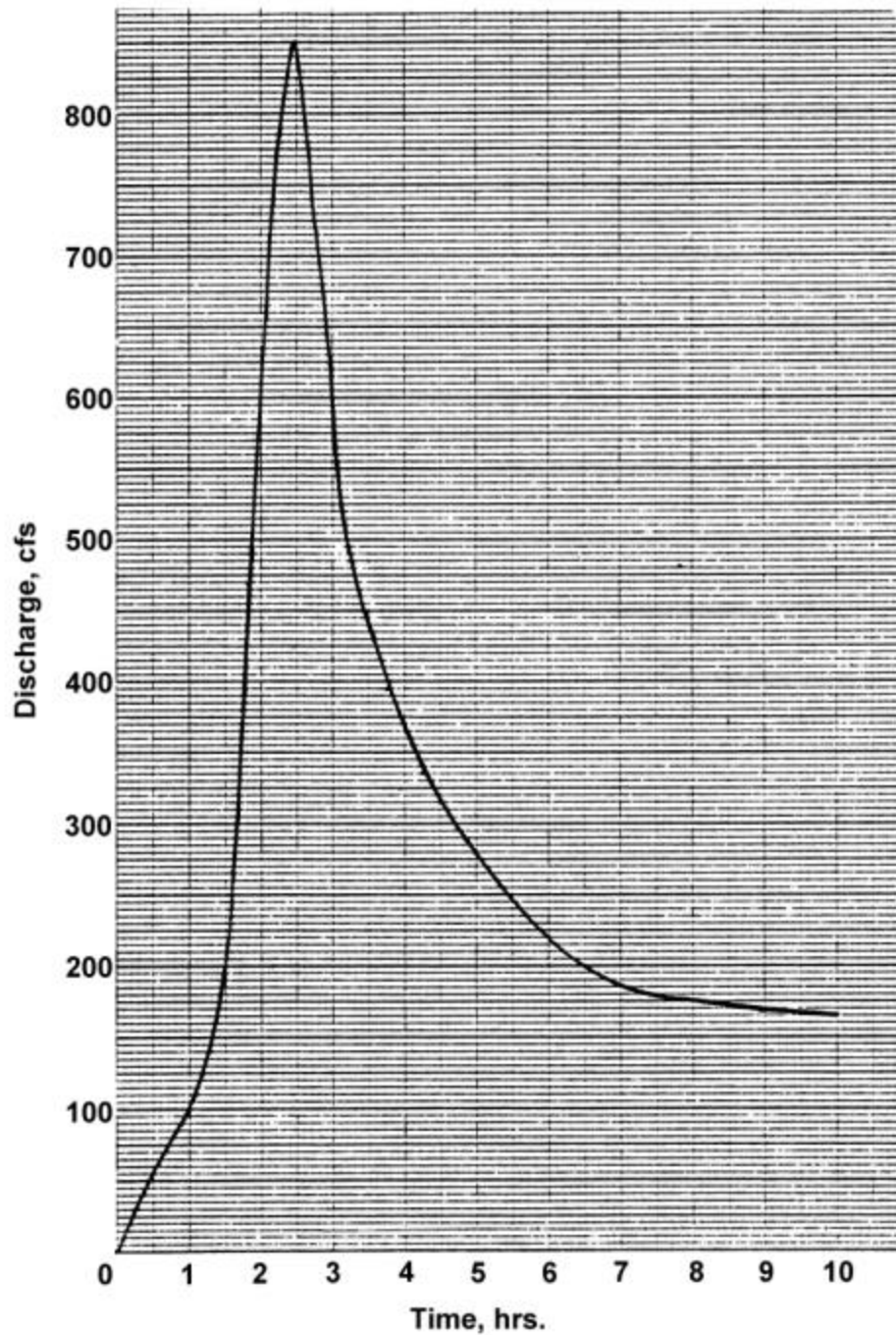S_2/dt - storage/routing interval, cubic feet/second

Figure 9.3 - Inflow Hydrograph for Routing Example

6. **Set-up operations table**. Column 1 contains the time at the selected increment, and column 2 contains the inflow taken from the inflow hydrograph (figure 9.3). The average inflow in column 3 is the average of the flow at the current time and the previous time interval. As an example, at a time of 0.50 hrs, the average inflow of 43 cfs is the average between 0.25 hrs (30 cfs) and 0.50 hrs (55 cfs).

Table 9.3 - Operations Table

(1) Time	(2) Inflow	(3) Avg. Inflow	(4) $S2/dt=O_2$	(5) O_2
(hrs)	(cfs)	(cfs)	(cfs)	(cfs)
0.00	0	0		
0.25	30	15		
0.50	55	43		
0.75	80	68		
1.00	100	90		
1.25	138	119		
1.50	190	164		
1.75	380	285		
2.00	610	495		
2.25	785	698		
2.50	850	818		
2.75	730	790		
3.00	620	676		
3.25	485	552		
3.50	440	463		
3.75	395	418		
4.00	370	383		
4.25	335	353		
4.50	315	325		

The last two columns (4 & 5) will be completed during the routing.

7. **Route the inflow through the detention pond**.

    The routing would include:

    a) Determine inflow, storage, and outflow for initial conditions. In many cases, the initial inflow, outflow, and storage will be 0.
    b) Subtract outflow (column 5) from column 4 and add average inflow (column 3) for the next time increment. The computed value is placed in column 4 for the next time increment. (In the table below under initial conditions, columns 4 and 5 are each 0. At the time of 0.25 hours, the average inflow is 15 cfs. Column 4, at the time of 0.25 hours, is equal to 0 - 0 + 15 = 15). As a further example, at the time of 0.75 hours, column 4 shows a value of 123 cfs; from figure 9.2, the outflow in column 5 is 11 cfs; the average inflow at time 1.00 hour is 90 cfs. Column 4 at 1.00 hours is 123 - 11 + 90 = 202).

Operations Table

(1) Time (hrs)	(2) Inflow (cfs)	(3) Avg. Inflow (cfs)	(4) S2/dt+02 (cfs)	(5) 0 (cfs)
0.00	0	0	0	0
0.25	30	15	15	1
0.50	55	43	57	2
0.75	80	68	~~123~~	~~11~~
1.00	100	~~90~~	*202	

* (123 - 11 + 90)

c) From the plot of $S_2/dt + O_2$ vs. O_2, determine the outflow O_2, for the computed value of $S_2/dt + O_2$. As examples, from figure 9.2, when $S_2/dt + O_2 = 123$, the outflow is 11 cfs; when $S_2/dt + O_2 = 202$, $O_2 = 19$ cfs.

Operations Table

(1) Time (hrs)	(1) Time (hrs)	(1) Time (hrs)	(1) Time (hrs)	(1) Time (hrs)
0.00	0.00	0.00	0.00	0.00
0.25	0.25	0.25	0.25	0.25
0.50	0.50	0.50	0.50	0.50
0.75	0.75	0.75	0.75	0.75
1.00	1.00	1.00	1.00	1.00

d) Repeat the steps until routing is complete.

The results of the partial routing indicate that the peak inflow has been reduced from a discharge of 850 cfs, to an outflow of 433 cfs. From the outlet rating curve (table 9.1) the maximum stage on the detention pond is 611.1 feet.

If required, the routing could be continued until the entire outflow hydrograph is developed.

Operations Table

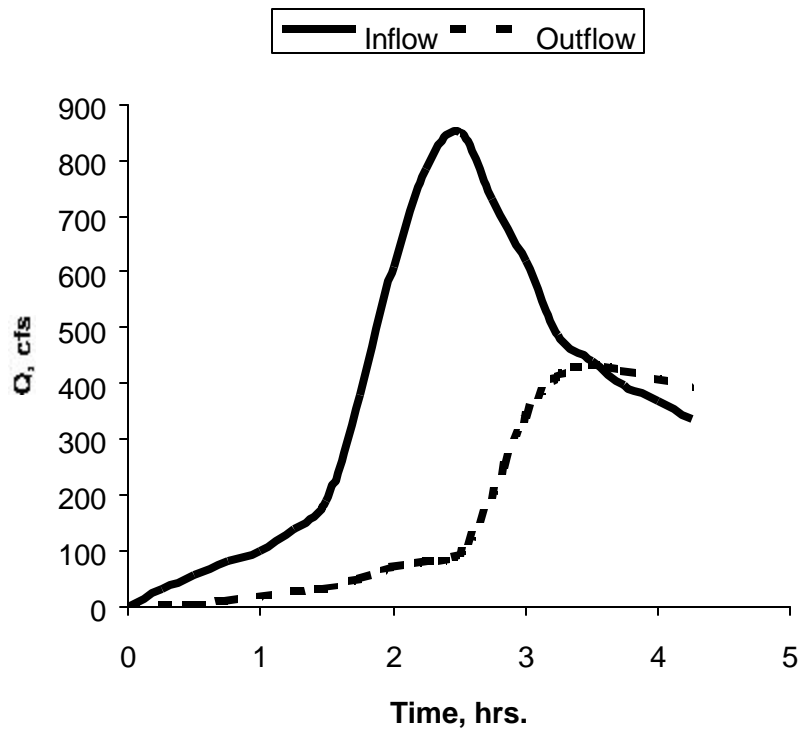| (1) Time (hrs)	(2) Inflow (cfs)	(3) Avg. Inflow (cfs)	(4) S2/dt+02 (cfs)	(5) 0 (cfs)
0.00	0	0	0	0
0.25	30	15	15	1
0.50	55	43	57	2
0.75	80	68	123	11
1.00	100	90	202	19
1.25	138	119	302	27
1.50	190	164	439	33
1.75	380	285	724	50
2.00	610	495	1169	70
2.25	785	698	1797	81
2.50	**850**	818	2534	95
2.75	730	790	3229	200
3.00	620	675	3704	343
3.25	485	552	3913	413
3.50	440	463	3963	**433**
3.75	395	418	3948	422
4.00	370	383	3809	408
4.25	335	353	3854	392

Figure 9.4 - Partial Inflow and Outflow Hydrographs for Routing Example

COMPUTER PROGRAMS

There are computer programs available that will perform detailed hydrologic analyses and routing. A big advantage to using a computer program is that once the computer model is "set-up", numerous options and scenarios can be analyzed with very little additional effort. The more popular computer programs include:

1. HEC-1 - developed by the Corps of Engineers. The program will generate hydrographs and perform routing (reference 44). This program can be downloaded at: www.hec.usace.army.mil/software/software_distrib/index.html.
2. TR-20 - developed by the Soil Conservation Service. The program will generate hydrographs and perform routing (reference 47).
3. DAMBRK - developed by the National Weather Service. The program is an unsteady-state model (flow rate is not assumed to be constant) which combines hydraulic and hydrologic techniques. It is able to accurately model flood-waves as they move downstream. Originally developed to model flood-wave produced by dam failures, the program can be used to route flows down channels, through basins, and will produce a flood profile (reference 15).
4. ILLUDAS - originally developed at the Road Research Laboratory in England, and later enhanced by the Illinois State Water Survey. The program uses a simplified routing technique, the runoff the characteristics from the basin, along with the rainfall to size storm sewers, to compute the storage needed to prevent sewer capacity from being exceeded. Suggested as a preliminary planning tool. (reference 43).
5. SWMM - Storm Water Management Model - developed under the sponsorship of the U.S. Environmental Protection Agency is a comprehensive urban stormwater analysis model that computes runoff, pollutant transport, detention storage, and treatment. The model is complex and is not really suited for analysis of a single detention pond, but is more applicable for analysis of complete storm sewer systems. (reference 42).
6. Others - In recent years other models have been developed that also generate runoff hydrographs, and design detention basins. Technical magazines such as "Civil Engineering" will typically carry information and advertisements relating to new developments in stormwater management modeling.

No matter which computer program that is used in the analysis and design of a detention basin, it is still the designer's responsibility to become completely familiar with the program, and to check the results. The results provided by the computer program are a function of the experience of the user and the data input. At no time should computer programs be used "blindly"; the results should **not** be treated as gospel.